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# Nucleon Spin with and without Hyperon Data: A New Tool for Analysis<sup>†</sup>

Marek Karliner<sup>1 ‡</sup>

and

Harry J. Lipkin<sup>1,2 §</sup>

<sup>1</sup> *School of Physics and Astronomy*

*The Raymond and Beverly Sackler Faculty of Exact Sciences*

*Tel Aviv University, 69978 Tel Aviv, Israel*

and

<sup>2</sup> *Department of Particle Physics*

*The Weizmann Institute of Science, 76100 Rehovot, Israel*

## Abstract

We present a simple explanation of the underlying physics in the use of hyperon decay data to obtain information about proton spin structure. We also present an alternative input using nucleon magnetic moment data and show that the results from the two approaches are nearly identical. The role of symmetry breaking is clarified while pointing out that simple models explaining the violation of the Gottfried sum rule via pion emission tend to lose the good SU(3) predictions from Cabibbo theory for hyperon decays.

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# 1 Introduction

The conventional analyses of proton spin structure make use of three experimental quantities to determine the values of the three contributions to the proton spin from the three flavors of quarks denoted by  $\Delta u$ ,  $\Delta d$  and  $\Delta s$ . The connection between two of the commonly used experimentally determined numbers to proton spin structure is reasonably clear and well established. The use of the third, obtained from data on weak decays of hyperons, rather than from data on the nucleon itself, involves assumptions about SU(3) flavor symmetry relations between nucleon and hyperon wave functions which have been challenged.

In this note we wish to spell out this problem and indicate how SU(3) symmetry breaking can be taken into account and also to present an alternative source for the third experimental parameter, the ratio of the proton and neutron magnetic moments, which depends only on the properties of the nucleon, and does not require any assumptions about hyperon spin structure.

Recent experiments of polarized deep inelastic scattering (DIS) provided us with high quality data for the spin structure functions of the proton, deuteron and neutron [1, 2, 3, 4]. These measurements are used to evaluate the first moments of the spin dependent structure functions which can be interpreted in terms of the contributions of the quark spins ( $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ ) to the total spin of the nucleon. The first results from the measurements of the proton spin structure function by the EM Collaboration [5] were very surprising, implying that  $\Delta\Sigma$  is rather small (about 10%) and that the strange *sea* is strongly polarized. More recent analysis [8],[9], incorporating higher-order QCD corrections, together with additional experimental data [3, 4], and new analyses of hyperon decays [6, 7], suggest that  $\Delta\Sigma$  is significantly larger than what was inferred from the EMC experiment, concluding that  $\Delta\Sigma \approx 0.24 \pm 0.04$  and  $\Delta s = -0.12 \pm 0.03$ .

The polarized deep inelastic scattering experiments measure contributions  $\Delta q$  of individual quarks to the proton spin, weighted by the square of the quark charge  $e_q$ ,

$$\Gamma_1^p = \left( \frac{1}{2} \sum_q e_q^2 \Delta q \right) \times \left[ 1 - \frac{\alpha_s}{\pi} + \mathcal{O} \left( \left( \frac{\alpha_s}{\pi} \right)^2 \right) + \dots \right] \quad . \quad (1)$$

Thus they measure a quantity proportional to  $4\Delta u + \Delta d + \Delta s$ . The proportionality constant includes perturbative QCD corrections which are known to be significant also at higher orders. The actual value of  $\Gamma_1$  is subject to a considerable experimental uncertainty, due to the unknown systematic error coming from the low- $x$  extrapolation beyond the measured region. In principle, one also needs to keep in mind that the higher-order corrections are different for the flavor singlet and flavor non-singlet parts of  $\Gamma_1$ . In this paper we focus on other issues, so for sake of simplicity we will use the most recent E143 result [4]

$\Gamma_1(Q^2 = 3 \text{ GeV}^2) = 0.132 \pm 0.003(\text{stat.}) \pm 0.009(\text{syst.})$ , and only the leading-order QCD correction. However, since all the perturbative QCD corrections have the same sign as the leading-order, we shall use here an “effective” value  $\alpha_s = 0.4$ , which is higher than the standard value at  $Q^2 = 3 \text{ GeV}^2$ . As we shall see, this simplification yields results which are still quite close to those of [8] and [9]. The Bjorken sum rule tells us that the neutron weak decay constant  $g_A = \Delta u - \Delta d$ .

Between these two measurements we obtain the values of two linear combinations of  $\Delta u(p)$ ,  $\Delta d(p)$  and  $\Delta s(p)$ ,

$$4\Delta u + \Delta d + \Delta s = 2.72 \quad (2)$$

$$\Delta u - \Delta d = 1.26 \quad (3)$$

Since these are the experimental quantities obtained directly from the data on deep inelastic scattering and  $G_A/G_V$  without SU(3) symmetry assumptions, we can use these as a base for our further analysis. We now need an additional third experimental input to determine the values of  $\Delta u$ ,  $\Delta d$  and  $\Delta s$ .

Up to this point the only assumption made about the proton wave function is that it has a good isospin and that the strangeness-conserving components of the weak axial current are isovectors. In order to obtain a value for  $\Delta s$  it is necessary to use additional data; e.g. the hyperon decay data commonly used.. However this requires additional assumptions about SU(3) flavor symmetry which is known to be broken. We now examine the underlying physics of this symmetry breaking.

Before we break the symmetry we need to know why we need it in the first place. We need isospin SU(2) symmetry in order to obtain information about proton spin structure from the neutron decay

$$g_A \equiv \frac{G_A}{G_V}(n \rightarrow p) = \Delta u(p) - \Delta d(p) = \Delta d(n) - \Delta u(n) \quad (4)$$

where we have used the Bjorken sum rule which relates the deep-inelastic data to  $g_A$  and isospin to relate the charged and neutral strangeness-conserving axial currents and to relate the proton and neutron wave functions. The neutron and proton are isospin mirrors which go into one another under the  $u \leftrightarrow d$  transformation.

Similarly we use SU(3) symmetry if valid to obtain information about proton spin structure from the  $\Sigma^-$  semileptonic decay

$$\frac{G_A}{G_V}(\Sigma^- \rightarrow n) = \Delta u(n) - \Delta s(n) = \Delta d(p) - \Delta s(p) \quad (5a)$$

$$\Delta s(\Sigma^-) - \Delta u(\Sigma^-) = \Delta u(n) - \Delta s(n) = \Delta d(p) - \Delta s(p) \quad (5b)$$

$$|G_V(\Sigma^- \rightarrow n)| = |G_V(n \rightarrow p)| \quad (5c)$$

where  $SU(3)$  relates the nucleon and  $\Sigma^-$  wave functions. The neutron and  $\Sigma^-$  are  $SU(3)$  mirrors which go into one another under the  $u \leftrightarrow s$  transformation.

Note that with precise data and  $SU(3)$  symmetry the value of  $(G_A/G_V)(\Sigma^- \rightarrow n)$  is sufficient to give us all the information needed for the spin structure of the proton. There is no need for the F and D parametrization. It is only when we want to improve statistics by also using other weak decays which involve the  $\Lambda$  that we need F and D. The  $\Sigma^-(dds) \rightarrow n(duu)$  is simple because the strangeness-changing current at the quark level is an  $s \rightarrow u$  transition which can only change the  $\Sigma^-$  into a neutron. On the other hand the same  $s \rightarrow u$  transition on a  $\Xi^-(dss)$  produces a  $(dsu)$  state which is a linear combination of a  $\Lambda$  and a  $\Sigma^0$ . How to separate this into the  $\Lambda$  and  $\Sigma^0$  requires an additional parameter that depends on the hadron wave functions. It is conventional to use the F and D parametrization for historical reasons, but there is no obvious physical reason to use these parameters rather than any others. For our purposes here it is sufficient to consider only the  $\Sigma^- \rightarrow n$  decay and see how the relations (5) are affected by  $SU(3)$  symmetry breaking.

We see that there are four physical quantities that enter into this relation:

- (1)  $G_A(\Sigma^- \rightarrow n)$
- (2)  $G_V(\Sigma^- \rightarrow n)$
- (3)  $\Delta u(n) - \Delta s(n)$
- (4)  $\Delta s(\Sigma^-) - \Delta u(\Sigma^-)$ .

When  $SU(3)$  is broken, these four quantities are no longer related, and we have to understand what the breaking does to these relations. This depends upon how  $SU(3)$  is broken. There is no model-independent way to allow for  $SU(3)$  breaking.

The quantity denoted by  $g_A$  is really a ratio of axial-vector and vector matrix elements. Both matrix elements can be changed by  $SU(3)$  symmetry-breaking, but it is only the axial matrix element that is relevant to the spin structure. The information from hyperon decays used in conventional treatments of spin structure is expressed in terms of D and F parameters which characterize the axial couplings. But there is the implicit assumption that the vector coupling is pure F and normalized by the conserved vector current, where the whole  $SU(3)$  octet of vector currents is conserved. Thus any attempts to parameterize  $SU(3)$  breaking in fitting hyperon data by defining “effective” D and F parameters immediately encounter the difficulty of how much of the breaking comes from the axial couplings and how much comes from the vector and the breakdown of the conserved vector currents for strangeness changing currents. The vector matrix element

is uniquely determined by Cabibbo theory in the SU(3) symmetry limit. The known agreement of experimental vector matrix elements with Cabibbo theory places serious constraints on possible SU(3) breaking in the baryon wave functions. On the other hand, the strange quark contribution to the proton sea is already known from experiment to be reduced roughly by a factor of two from that of a flavor-symmetric sea [13]. This is expected to violate the  $\Sigma^- \leftrightarrow n$  mirror symmetry since it is hardly likely that the strange sea should be enhanced by a factor of two in the  $\Sigma^-$ . Yet Cabibbo theory requires retaining the relation between the vector matrix elements (5c).

For insight into how to insert flavor asymmetry into procedures for obtaining the spin structure of baryons from experimental data we first note that two mechanisms have been introduced for breaking flavor symmetry in the antiquark distributions in the nucleon.

- (1) Introducing a pion cloud, without other pseudoscalar mesons, while maintaining overall isospin symmetry [10].
- (2) Reducing the strange contribution in the sea, thereby breaking SU(3) symmetry [12, 14] .

In both cases, the question arises of whether this symmetry breaking is consistent with the experimental confirmation of the predictions from Cabibbo theory for the vector currents and the experimental agreement of the axial vector weak transitions with SU(3) symmetry relations.

The essential physics of the mechanism (1) is seen in the simple quark diagram for pion emission from a valence  $u$  quark.

$$u \rightarrow u + G \rightarrow u + \bar{q}q \rightarrow (u\bar{q})_P + q \quad (6)$$

where  $G$  denotes gluons and  $(u\bar{q})_P$  denotes a pseudoscalar meson with the quark content  $(u\bar{q})$ . Although flavor symmetry suggests that the probabilities of producing  $\bar{u}$  and  $\bar{d}$  antiquarks via this diagram must be equal, the constraint that the pseudoscalar meson constructed in this way must be a pion leads to the result that the probability of producing a  $\bar{d}$  antiquark is double that of producing a  $\bar{u}$ . This factor of two can be seen by comparing the  $(u\bar{d})_P$  and  $(u\bar{u})_P$  wavefunctions. Whereas  $(u\bar{d})_P$  is a pure  $\pi^+$ , the  $(u\bar{u})_P$  wave function is a linear combination of the  $\pi^0$ ,  $\eta$  and  $\eta'$  wave function with a probability of only (1/2) of fragmenting into a  $\pi^0$ . Neglecting the  $\eta$  and  $\eta'$  contributions to a pion cloud model introduces a breaking of nonet symmetry and SU(3) symmetry while conserving isospin. In this model the neutron  $\beta$  decay occurs both in the valence nucleon and the pion cloud, and the isospin symmetry of the overall wave function preserves the conserved vector current and the Bjorken sum rule. The excess of  $\bar{d}$  antiquarks over  $\bar{u}$  can explain the observed violation of the Gottfried sum rule [11].

This mechanism breaks SU(3) and a simple toy-model calculation shows

that it can introduce serious disagreements with Cabibbo theory for strangeness changing transitions and in particular with the experimentally verified predictions for hyperon decay.

To see this, we write the physical nucleon wave function as a mixture of a “bare” nucleon and a nucleon plus a pseudoscalar meson,

$$|p_{phys}\rangle = \cos(\phi) \cdot |p_{val}\rangle + \frac{\sin(\phi)}{\sqrt{3}} \cdot [ |p\pi^0\rangle - \sqrt{2} \cdot |n\pi^+\rangle ] \quad (7)$$

where  $|p_{val}\rangle$  denotes the standard quark-model proton wave function and  $|N\pi\rangle$  denotes a nucleon-pion wave function with angular momentum ( $J = 1/2$ ) and isospin ( $I = 1/2$ ). The factor  $\sqrt{2}$  which breaks the Gottfried sum rule appears here as an isospin Clebsch-Gordan coefficient.

We now investigate the action of the strangeness-changing components of the charged weak vector current on the proton wave function (7). At zero-momentum transfer, these are just the  $V$  spin raising and lowering operators, denoted by  $V_{\pm}$ , which generate  $u \leftrightarrow s$  and  $\bar{s} \leftrightarrow \bar{u}$  transitions at the quark level. The requirement that the proton and  $\Lambda$  are members of the same SU(3) octet gives the two conditions:

$$V_+ |p_{phys}\rangle = 0 \quad (8)$$

$$P(I=0) \cdot V_- |p_{phys}\rangle = \frac{\sqrt{6}}{2} |\Lambda_{phys}\rangle \quad (9)$$

where  $P(I=0)$  denotes a projection operator which projects out the  $I=0$  component of the wave function and  $|\Lambda_{phys}\rangle$  denotes the normalized physical  $\Lambda$  wave function. These two conditions required by Cabibbo theory are manifestly violated by the proton wave function (7) except for the trivial case  $\phi=0$ : (i) the left hand side of the condition (8) is a  $pK^+$  state and does not vanish; (ii) the state  $|\Lambda_{phys}\rangle$  defined by the condition (9) is not normalized but satisfies

$$\begin{aligned} \langle \Lambda_{phys} | \Lambda_{phys} \rangle &= \frac{2}{\sqrt{6}} \cdot \langle \Lambda_{phys} | P(I=0) \cdot V_- | p_{phys} \rangle = \\ &= \cos^2(\phi) + (5/6) \sin^2(\phi) = 1 - (1/6) \sin^2(\phi) \end{aligned} \quad (10)$$

The matrix element  $\langle \Lambda_{phys} | P(I=0) \cdot V_- | p_{phys} \rangle$  appearing in eq. (10) is just the transition matrix measured experimentally in the semileptonic vector  $\Lambda \rightarrow p$  decay. Thus the inconsistency in eq. (10) is not only a disagreement with Cabibbo theory; it is also a disagreement with experiment. The nature of this inconsistency is illuminated by noting that production of a state of strangeness +1 by the action of the SU(3) generator  $V_+$  when acting on a proton model wave function indicates that this proton wave function is not a pure SU(3) octet but contains a **27** admixture. When SU(3) symmetry is restored in this model wave

function by adding the correct admixture of  $\Lambda K$ ,  $\Sigma K$  and  $p\eta_8$  states in (7), the action of the operator  $V_+$  on these components produces the  $pK^+$  state with just the right phase to cancel the  $pK^+$  state produced on the nucleon-pion state.

It is just these extra  $\Lambda K$ ,  $\Sigma K$  and  $p\eta_8$  components in the nucleon wave function which are needed to restore the normalization of the physical  $\Lambda$  state  $|\Lambda_{phys}\rangle$ . This shows that if baryon-meson components are added to the proton and  $\Lambda$  wave functions, the physical  $\Lambda$  state is required by Cabibbo theory to decay also to  $\Lambda K$  and  $\Sigma K$  components in the proton wave function. Leaving these components out of the proton leads to disagreement with the semileptonic  $\Lambda \rightarrow p$  vector decay. If the  $\Lambda$  wave function is evaluated explicitly from the lhs of eq. (9), it will include  $NK$  components with a kaon cloud, along with a  $\Sigma\pi$  component containing a pion cloud. If the kaon cloud is not included, the disagreement in eq. (10) is much worse, with the coefficient (1/6) replaced by (2/3).

We thus see that in any model which includes a pion cloud in the proton wave function, SU(3) breaking must reduce the kaon cloud relative to the pion cloud from the value in the symmetry limit. This breaking seems to have a serious effect on the matrix elements of the strangeness changing current responsible for hyperon decays. We will not address this issue further here.

A model which has been suggested [12] for breaking SU(3) via the mechanism (2) keeps all the good results of Cabibbo theory by introducing a flavor asymmetric sea with no net flavor quantum numbers into a baryon wave function whose valence quarks satisfy SU(6) symmetry and whose sea is *the same* for all baryons.

The baryon wave function can be written,

$$\Psi(B) = \psi_{val}(B) \cdot \phi_{sea}(Q = 0) \quad (11)$$

where  $\psi_{val}(B)$  denotes the valence quark wave function obtained from the SU(6) quark model and  $\phi_{sea}(Q = 0)$  denotes a sea with zero electric charge which may be flavor asymmetric.

The operation of any charged current operator  $J_\pm$  on this baryon wave function is then

$$J_\pm \Psi(B) = \{J_\pm \psi_{val}(B)\} \cdot \phi_{sea}(Q = 0) + \psi_{val}(B) \cdot \phi'_{sea}(Q = \pm 1) \quad (12)$$

where  $\phi'_{sea}(Q = \pm 1)$  denote charged seas obtained by acting on the neutral sea with the charged current. The exact structures of  $\phi'_{sea}(Q = \pm 1)$  depend upon the details of the wave function, but are irrelevant for our purposes. Since the overlaps of the identical neutral seas gives a factor unity and the overlap of a neutral sea and a charge sea vanishes, we see that the matrix elements of the charged current between any two baryon states  $B$  and  $B'$  is given by

$$\langle B' | J_\pm | B \rangle = \langle B_{val} | J_\pm | B_{val} \rangle \quad (13)$$

We thus see that all charged current matrix elements are given by the valence quarks. This provides an explicit justification for the hand-waving argument [12] in the toy model that in the hyperon decay the sea behaves as a spectator. In particular, for the strangeness changing vector charge producing the  $\Sigma^- \rightarrow n$  decay,

$$\langle n | V_+ | \Sigma^- \rangle = 1 \quad (14)$$

consistent with Cabibbo theory.

Unlike the charged current, the matrix elements of the neutral components of the weak currents *do* have sea contributions, and these contributions are observed in the DIS experiments. The SU(3) symmetry relations (5) are no longer valid. However, the weaker relation obtained from current algebra [14] still holds.

$$\frac{G_A}{G_V}(\Sigma^- \rightarrow n) = \frac{\langle n | \Delta u - \Delta s | n \rangle - \langle \Sigma^- | \Delta u - \Delta s | \Sigma^- \rangle}{2} \quad (15)$$

Relation (15) is the SU(3) analogue of the familiar isospin relation

$$\frac{G_A}{G_V}(n \rightarrow p) = \frac{\langle p | \Delta u - \Delta d | p \rangle - \langle n | \Delta u - \Delta d | n \rangle}{2} \quad (16)$$

## 2 Getting $\Delta u$ , $\Delta d$ and $\Delta s$ From Data

We have seen that two of the three parameters needed to determine the three quantities  $\Delta u$ ,  $\Delta d$  and  $\Delta s$  are obtainable from the experimental data on deep inelastic scattering of polarized leptons on the proton and from the value of  $G_A/G_V$  interpreted via the Bjorken sum rule for the neutron decay. There are several ways to continue. We first note that we can combine (2) and (3) to project out an isoscalar component of the spin structure functions

$$\Delta u + \Delta d + (2/5) \cdot \Delta s = 0.333 \quad (17)$$

The conventional procedure for obtaining the needed additional experimental number to define three quantities is to use data from weak hyperon decays, interpreted using SU(3) symmetry via eqs. (3). by what is effectively an SU(3)-flavor rotation of the Bjorken sum rule. This procedure has the advantage of dealing only with the three parameters  $\Delta u(p)$ ,  $\Delta d(p)$  and  $\Delta s(p)$  which are the total contributions of quark spins of each flavor to the proton spin. There is no need to break up these contributions into valence and sea contributions nor to quark and antiquark.

However, flavor SU(3) is known to be broken by quark mass differences which suppress the number of  $s\bar{s}$  pairs created by gluons in the sea relative to the



number of  $u\bar{u}$  and  $d\bar{d}$  pairs. This has been borne out by neutrino experiments which suggest a suppression factor of roughly 2.

We are thus led to breaking up the quark contributions into valence and sea contributions. This is required on the one hand to provide a mechanism for taking into account the SU(3) symmetry-breaking in the sea and also to provide a description of the experiments which specifically measure the antiquark content in the sea.

At this stage we wish to avoid a proliferation of models each with many different ad hoc assumptions and many free parameters. We find that this can be done in two ways (1) the conventional use of the hyperon weak decays; (2) a new approach using the ratio of the proton and neutron magnetic moments. In both cases we use the model discussed above in which the sea is not necessarily flavor symmetric.

Method (1) assumes, as in the discussion of the model, that the sea is a spectator in the weak transitions. Method (2) assumes that the sea is a spectator in the determination of the nucleon magnetic moments.

Both assumptions can be questioned and justified only by hand-waving at this stage. The hand-waving for method (1) points to the success of the model for Cabibbo theory and the observation that the contribution from a sea which violates flavor symmetry by a factor of two must be minimum. The hand-waving for method (2) notes that since quarks and antiquarks of the same flavor contribute with opposite signs to magnetic moments, it is reasonable to assume a cancellation between the integrals of quark and antiquark momentum distributions which contribute to the magnetic moment. This can be true even if there is a large flavor asymmetry in the sea implied by the observed experimental violation of the Gottfried sum rule [11].

What is particularly interesting is that each of the two approaches makes assumptions that can be questioned, but that although these assumptions are qualitatively very different, both give very similar results. The use of hyperon data requires a symmetry assumption between nucleon and hyperon wave functions, which is not needed for the magnetic moment method. But the use of magnetic moments requires that the sea contribution to the magnetic moments be negligible, which is not needed for the hyperon decay method.

We explore both approaches and two possibilities for the strange quark content of the sea:

- (1) that the sea is SU(3) symmetric,
- (2) that the baryon wave function is described by eq. (11) and the strange quark contribution differs from the nonstrange in the manner described by the parameter  $\epsilon$

$$(1 + \epsilon)\Delta s_S = \Delta u_S = \Delta d_S \quad (18)$$

proposed in the model [12], which incorporates the weak decay data with the polarized DIS results and also maintains the good results of Cabibbo theory for weak decays.

## A. The use of Hyperon Decay Data and SU(3)

### 1. With a flavor-symmetric sea.

The standard analysis obtains an additional function of  $\Delta u(p)$ ,  $\Delta d(p)$  and  $\Delta s(p)$  from hyperon weak decay data. Rather than using the SU(3) analysis with the D and F parametrization, we use a mathematically equivalent formulation which is more transparent physically and more easily extended to introduce SU(3) breaking. The best fit to the isoscalar octet linear combination of  $\Delta u(p)$ ,  $\Delta d(p)$  and  $\Delta s(p)$  obtained from hyperon data gives.

$$\Delta u + \Delta d - 2\Delta s = 0.6 \quad (19)$$

We now note that the relations obtained from the weak decay data (3) and (19) depend only upon the valence quarks if the sea is SU(3)-symmetric. Since there are no valence strange quarks in the proton, we obtain

$$\Delta d_V = -0.33 \quad (20a)$$

$$\Delta u_V = 0.93 \quad (20b)$$

$$\Delta u_S + \Delta d_S + (2/5) \cdot \Delta s = -0.27 \quad (20c)$$

where the subscripts  $V$  and  $S$  denote valence and sea.

If we now assume that the sea is SU(3) flavor-symmetric ( $\epsilon = 0$ ) and substitute into eqs. (18) and (20c), we immediately obtain

$$\Delta u_S = \Delta d_S = \Delta s_S = \Delta s = -0.11 \quad (21a)$$

Thus

$$\Delta d = -0.44 \quad (21b)$$

$$\Delta u = 0.82 \quad (21c)$$

$$\Delta \Sigma = 0.27 \quad (21d)$$

These are the conventional values obtained by the mathematically equivalent D and F parametrization.

## 2. With SU(3) for Valence Quarks and Breaking in the Sea

We now assume that only the valence quarks contribute to weak decays and that the sea is not SU(3) symmetric but is still the same for all octet baryons, then eqs. (17), (20a) and (20b) are still valid. If we now assume that  $\Delta s$  in the sea is suppressed by a factor of 2 relative to  $\Delta u$  and  $\Delta d$  ( $\epsilon = 1$ ) we obtain instead of (21a),

$$\Delta u_S = \Delta d_S = 2 \cdot \Delta s_S = -0.12 \quad (22)$$

Thus

$$\Delta d = -0.45 \quad (23a)$$

$$\Delta u = 0.81 \quad (23b)$$

$$\Delta \Sigma = 0.30 \quad (23c)$$

This is the well known result that the values of  $\Delta u$  and  $\Delta d$  obtained from the standard analysis of the data are insensitive to SU(3) breaking in the sea, and only  $\Delta s$  is changed.

## B. The use of Nucleon Magnetic Moment Data

### 1. With a flavor-symmetric sea

Rather than using hyperon weak decay data and assuming SU(3) symmetry, we can obtain the needed alternative experimental input from nucleon magnetic moments, under the assumption that these are proportional to the valence quark contributions to the nucleon spin,  $\Delta d_V$  and  $\Delta u_V$ , weighted by the quark charges, and using isospin symmetry to relate proton and neutron wave functions.\*

The neglect of sea contributions might be justified because their quark and antiquark contributions to the magnetic moments have opposite sign and tend to cancel<sup>†</sup> We then obtain

$$\frac{\mu_p}{\mu_n} = \frac{2\Delta u_V(p) - \Delta d_V(p)}{2\Delta u_V(n) - \Delta d_V(n)} = \frac{2\Delta u_V(p) - \Delta d_V(p)}{2\Delta d_V(p) - \Delta u_V(p)} = -\frac{2.79}{1.91} \quad (24a)$$

This gives

$$\frac{\Delta u_V(p)}{\Delta d_V(p)} = -3.56 \quad (24b)$$

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\*That the values of  $\Delta d_V$  and  $\Delta u_V$  obtained from several models fit the SU(6) prediction  $-(3/2)$  for the magnetic moment ratio to better than 10% under this assumption has been noted in [15].

<sup>†</sup>Clearly, the total numbers of quarks and antiquarks of a given flavor are equal, but in order for the cancellation to occur, the integrals over  $x$  of the corresponding polarization distributions must be equal as well.

Assuming that polarizations of the light sea quarks are equal,  $\Delta u_S = \Delta d_S$ , their respective contributions in eq. (3) cancel each other, and we can now solve eqs. (3) and (24b) for  $\Delta d_V$  and  $\Delta u_V$ , obtaining

$$\Delta d_V = -0.28 \quad (24c)$$

$$\Delta u_V = 0.98 \quad (24d)$$

$$\Delta u_S + \Delta d_S + (2/5) \cdot \Delta s = -0.37 \quad (24e)$$

If we now assume that the sea is SU(3) flavor-symmetric ( $\epsilon = 0$ ) we immediately obtain

$$\Delta u_S = \Delta d_S = \Delta s_S = -0.16 \quad (25a)$$

$$\Delta d = -0.43 \quad (25b)$$

$$\Delta u = 0.83 \quad (25c)$$

$$\Delta \Sigma = 0.24 \quad (25d)$$

## 2. With flavor-symmetric breaking in the sea

If we now assume that  $\Delta s$  in the sea is suppressed by a factor of 2 relative to  $\Delta u$  and  $\Delta d$  ( $\epsilon = 1$ ) we obtain instead of (25a)

$$\Delta u_S = \Delta d_S = 2 \cdot \Delta s_S = -0.17 \quad (26a)$$

$$\Delta d = -0.45 \quad (26b)$$

$$\Delta u = 0.81 \quad (26c)$$

$$\Delta \Sigma = 0.28 \quad (26d)$$

We thus see that the results for  $\Delta u$  and  $\Delta d$  remain essentially the same, independently of whether the additional data are obtained from hyperon decays or magnetic moments, and of whether the sea is flavor symmetric or the strange quark contribution is reduced by a factor of two. Only  $\Delta s$  is changed.

## Conclusions

We now see that the results for the contributions of the nonstrange quarks,  $\Delta u$  and  $\Delta d$ , are determined primarily by the DIS scattering and by the neutron decay and are essentially independent of whether hyperon weak decay or nucleon magnetic moment data are used to provide a third experimental input, and whether one assumes an exact or seriously broken flavor SU(3) symmetry.

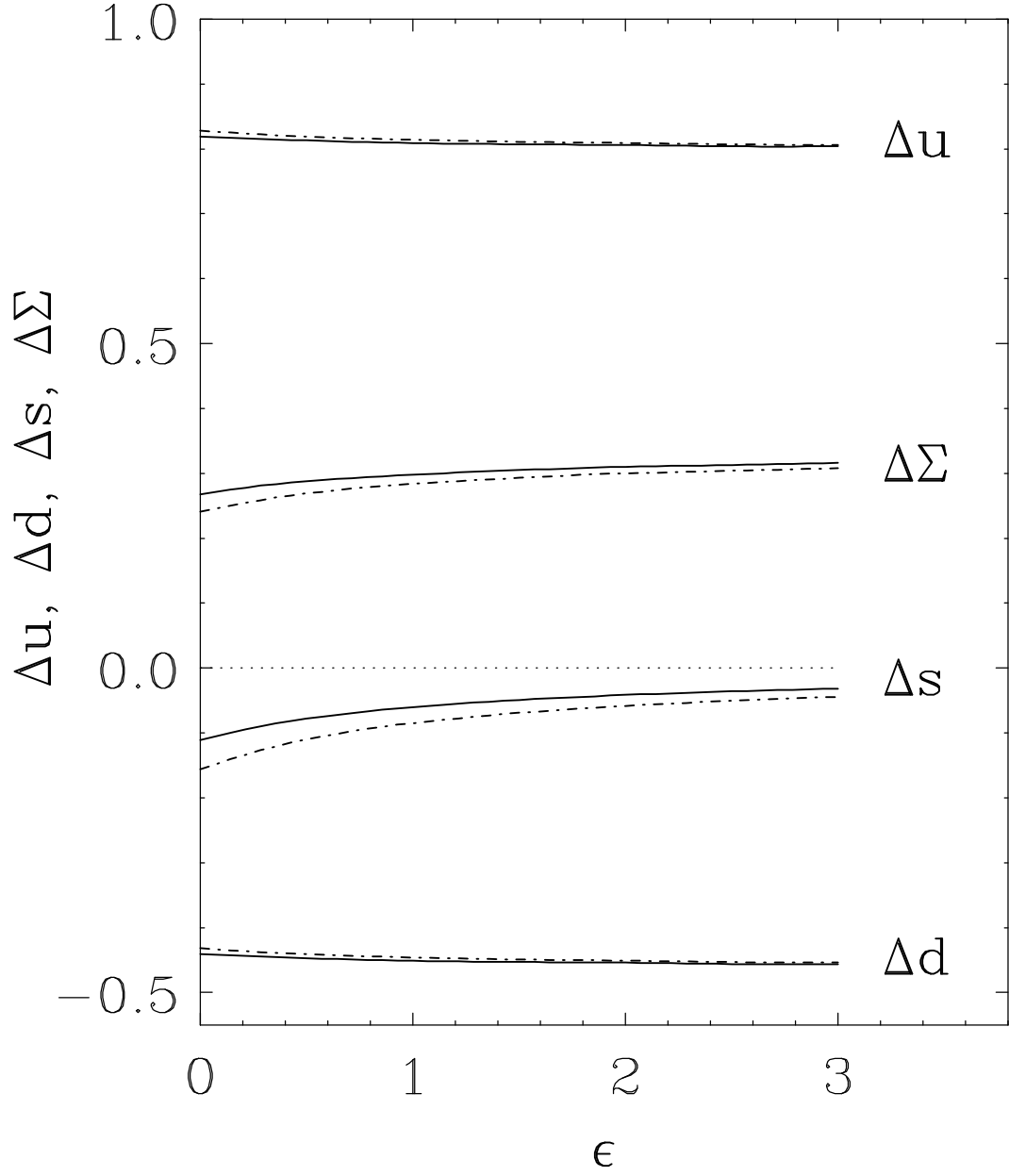
The strange quark contribution  $\Delta s$  is  $-0.11$  when hyperon decay is used and  $-0.16$  when magnetic moments are used with an  $SU(3)$  symmetric sea. Both are reduced by a factor of roughly two when the strange sea is reduced by a factor of two relative to the nonstrange sea ( $\epsilon = 1$ ). But in any case all results are consistent within two standard deviations of the value  $\Delta s = -0.1$  if we assume an experimental error of 25%. Since the  $SU(3)$ -breaking factor of two is determined only from measurement of unpolarized structure functions, it is of interest to find other experiments which measure  $\Delta s$  directly with greater precision.

The valence quark contributions to  $\Delta u_V$  and  $\Delta d_V$  differ by 0.05, depending upon whether hyperon data or nucleon magnetic moments are used to determine them. This can clearly be attributed to the difference in validity of the underlying assumptions in the two cases. Nevertheless, the difference between the values of the total contributions of  $\Delta u$  and  $\Delta d$  to the proton spin is much smaller, 0.01. The values of  $\Delta\Sigma$  obtained in the two methods differ by 0.03 or less. What is remarkable here is that these differences are so small considering that their underlying assumptions are so different. This effect is illustrated in Figure 1, where we plot  $\Delta\Sigma$  and  $\Delta s$  extracted in the two approaches, for somewhat wider range of the strangeness suppression parameter,  $0 \leq \epsilon \leq 3$ .

The question how flavor symmetry is broken remains open. We have pointed out that model builders must keep track of how proposed  $SU(3)$  symmetry breaking effects may effect the good  $SU(3)$  results for hyperon decays obtained from Cabibbo theory and confirmed by experiment. The observed violation of the Gottfried sum rule remains to be clarified, along with the experimental question of whether this violation of  $\bar{u} - \bar{d}$  flavor symmetry in the nucleon exists for polarized as well as for unpolarized structure functions. The question of how  $SU(3)$  symmetry is broken in the baryon octet can be clarified by experimental measurements of  $\Lambda$  polarization in various ongoing experiments [16].

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**Fig. 1.**  $\Delta u$ ,  $\Delta d$ ,  $\Delta s$  and  $\Delta \Sigma$  as function of  $\epsilon$ , using hyperon data (continuous line) and using ratio of magnetic moments (dash-dotted line).

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